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(54) HOT-ROLLED STEEL SHEET, ELECTRIC RESISTANCE WELDED STEEL PIPE, RECTANGULAR STEEL PIPE, LINE PIPE, AND BUILDING STRUCTURE

(57) To provide an electric resistance welded steel pipe and a rectangular steel pipe with high buckling resistance, a hot-rolled steel sheet used as a material for these pipes, and a line pipe and a building structure using these. A hot-rolled steel sheet with a specific chemical composition, wherein a steel microstructure at the center of the sheet thickness of the hot-rolled steel sheet contains 70% or more and 98% or less by volume of ferrite and bainite in total, the remainder being one or two or more selected from pearlite, martensite, and austenite, has an average grain size of 15.0 μm or less, has a CP value of 0.090 or less as determined using a specific formula, has a tensile strength of 400 MPa or more, and has a yield ratio of 90% or less, an electric resistance welded steel pipe and a rectangular steel pipe using the hot-rolled steel sheet, and a line pipe and a building structure using these.

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Description

Technical Field

[0001] The present invention relates to an electric resistance welded steel pipe and a rectangular steel pipe, a hot-rolled steel sheet used as a material for these pipes, and a line pipe and a building structure using these.

Background Art

[0002] An electric resistance welded steel pipe or a roll-formed rectangular steel pipe used for a line pipe or a building structure is required to have high strength in order to withstand an internal pressure of a fluid flowing inside and a load from the outside. At the same time, it is also required to have high buckling resistance from the perspective of earthquake resistance.

[0003] An electric resistance welded steel pipe or a roll-formed rectangular steel pipe (hereinafter sometimes referred to as a "rectangular steel pipe") uses a hot-rolled steel sheet (hot-rolled steel strip) as a material. This is cold-rolled to form a cylindrical open pipe, and a butt portion is subjected to electric resistance welding (sometimes referred to as electrical resistance welding) to form a round steel pipe. An electric resistance welded steel pipe is produced by adjusting the outer diameter and the roundness using a forming roller disposed outside the round steel pipe. A rectangular steel pipe is produced by further roll-forming the round steel pipe into a rectangular shape using a roll with a target polygonal hole shape. The method for producing a rectangular steel pipe by roll forming advantageously has higher productivity than a method for producing a steel pipe by press bend forming. However, a high tensile strain is applied in the pipe axis direction during roll forming, and an electric resistance welded steel pipe or a roll-formed rectangular steel pipe therefore has problems of low ductility in the pipe axis direction and low buckling resistance. Furthermore, a material to be subjected to roll forming is required to select an appropriate hot-rolled steel sheet (hot-rolled steel strip) in consideration of a decrease in ductility due to the roll forming.

[0004] Furthermore, in an electric resistance welded steel pipe or a roll-formed rectangular steel pipe, as the wall thickness increases, working strain during roll forming increases, the ductility further decreases, and the buckling resistance further decreases.

[0005] In response to such requirements, for example, Patent Literature 1 discloses a high-strength hot-rolled steel sheet with high uniform elongation after cold working, which is a steel containing, on a weight basis, C: 0.04% to 0.25%, N: 0.0050% to 0.0150%, and Ti: 0.003% to 0.050% and having an equivalent carbon content (Ceq.) in the range of 0.10% to 0.45% as determined using a predetermined formula and in which a pearlite phase ranges from 5% to 20% by area and TiN with an average particle size in the range of 1 to 30 μm is dispersed in the steel at a ratio of 0.0008% to 0.015% by weight.

[0006] Patent Literature 2 discloses a thick hot-rolled steel sheet for a rectangular steel pipe for a building structural member with a low yield ratio, which has a composition containing, on a mass percent basis, C: 0.07% to 0.18%, Mn: 0.3% to 1.5%, P: 0.03% or less, S: 0.015% or less, Al: 0.01% to 0.06%, and N: 0.006% or less, with the balance being Fe and incidental impurities, and has a microstructure including ferrite as a main phase and pearlite or pearlite and bainite as a second phase, and in which a second phase frequency defined by a predetermined formula ranges from 0.20 to 0.42, and an average grain size including the main phase and the second phase ranges from 7 to 15 μm.

[0007] Patent Literature 3 discloses an electric resistance welded steel pipe for a line pipe with a low yield ratio, characterized in that a dislocation introduced in a forming process is pinned by a carbon atom cluster, a fine carbide, and a Nb carbide during tempering after pipe production.

[0008] Patent Literature 4 discloses a low-yield-ratio rectangular steel pipe made of a hot-rolled steel sheet characterized in that ferrite is a main phase, a second phase frequency ranges from 0.05 to 0.15, a second phase area fraction ranges from 3% to 15%, and the average grain size of the main phase and the second phase at a quarter thickness of the steel sheet ranges from 10 to 25 μm.

[0009] Patent Literature 5 discloses a rectangular steel pipe that is produced by hot forming and has high deformability and toughness.

Citation List

Patent Literature

[0010]

PTL 1: Japanese Unexamined Patent Application Publication No. 7-224351
PTL 2: Japanese Patent No. 5589885
PTL 3: Japanese Patent No. 6052374

PTL 4: Japanese Patent No. 7031477
PTL 5: Japanese Unexamined Patent Application Publication No. 2004-330222

Summary of Invention

Technical Problem

[0011] In these techniques, however, the characteristics at the time of tensile deformation, that is, suppression of necking or breakage of a tensile portion, have been studied, but local buckling in bending deformation or compressive deformation of an electric resistance welded steel pipe or a rectangular steel pipe has not been sufficiently studied.

[0012] Furthermore, as described in Patent Literature 3 and Patent Literature 5, a steel pipe subjected to heat treatment after pipe production or a steel pipe produced by hot forming has a large elongation at yield, is likely to have nonuniform deformation, and cannot have sufficient buckling resistance.

[0013] The present invention has been made in view of these circumstances and aims to provide an electric resistance welded steel pipe or a rectangular steel pipe with high buckling resistance and a hot-rolled steel sheet used as a material thereof. The present invention also aims to provide a line pipe or a building structure using the electric resistance welded steel pipe or the rectangular steel pipe.

[0014] The term "high buckling resistance", as used herein, means that the proof strength increase rate τ (= σmax/σy) in an axial compression test satisfies $\tau \geq 4.0 \times (t/D) + 0.85$ in an electric resistance welded steel pipe and $\tau \geq 3.0 \times (t/B) + 0.85$ in a rectangular steel pipe. t denotes the wall thickness (mm) of the electric resistance welded steel pipe or the rectangular steel pipe, D denotes the outer diameter (mm) of the electric resistance welded steel pipe, B denotes the side length (mm) of the rectangular steel pipe, σy denotes the yield stress (N/mm^2 (= MPa)) of a base metal portion of the electric resistance welded steel pipe or a flat portion of the rectangular steel pipe, and σmax denotes the maximum stress intensity (N/mm^2) in the axial compression test. When the cross-sectional shape of the rectangular steel pipe is a polygon with different side lengths, the average value of the side lengths is defined as the side length B of the rectangular steel pipe. In the present invention, the hot-rolled steel sheet as the material includes a hot-rolled steel strip.

Solution to Problem

[0015] As a result of extensive studies to solve the above problems, it has been found that the buckling resistance of a cold-formed electric resistance welded steel pipe or a cold-formed rectangular steel pipe can be improved by reducing the yield ratio of the cold-formed electric resistance welded steel pipe or the cold-formed rectangular steel pipe and reducing the logarithmic standard deviation of an equivalent plastic strain distribution during deformation. That is, it has been found that as the logarithmic standard deviation decreases, the variation in plastic strain during deformation decreases, the plastic strain is uniformly distributed, and the strain is less likely to concentrate on a specific portion, so that local buckling is less likely to occur. It has also been found that the electric resistance welded steel pipe or the rectangular steel pipe can be produced by using, as a material, a hot-rolled steel sheet with a small logarithmic standard deviation of an equivalent plastic strain distribution during deformation. The present invention has been completed on the basis of these findings and has the following gist.

[1] A hot-rolled steel sheet having a chemical composition, on a mass percent basis,

C: 0.030% or more and 0.300% or less,
Si: 0.010% or more and 0.500% or less,
Mn: 0.30% or more and 2.50% or less,
P: 0.050% or less,
S: 0.0200% or less,
Al: 0.005% or more and 0.100% or less, and
N: 0.0100% or less,
the balance being Fe and incidental impurities,
a steel microstructure at a center of a sheet thickness of the hot-rolled steel sheet
contains 70% or more and 98% or less by volume of ferrite and bainite in total,
the remainder being one or two or more selected from pearlite, martensite, and austenite,
has an average grain size of 15.0 μm or less,
has a CP value of 0.090 or less as determined using the following formula (1),
has a tensile strength of 400 MPa or more, and
has a yield ratio of 90% or less.

CP = (total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less than 20 μm)/(total length of high-angle grain boundaries) (1)

[2] The hot-rolled steel sheet according to [1], further containing, in addition to the chemical composition, on a mass percent basis, one or two or more selected from

Nb: 0.100% or less,
V: 0.100% or less,
Ti: 0.150% or less,
Cr: 0.50% or less,
Mo: 0.50% or less,
Cu: 0.50% or less,
Ni: 0.50% or less,
Ca: 0.0050% or less,
B: 0.0050% or less,
Mg: 0.020% or less,
Zr: 0.020% or less, and
REM: 0.020% or less.

[3] The hot-rolled steel sheet according to [1] or [2], wherein a logarithmic standard deviation of an equivalent plastic strain distribution after application of an 8.0% tensile strain is 0.70 or less.
[4] An electric resistance welded steel pipe including a base metal portion and an electric resistance weld,

wherein the electric resistance welded steel pipe has a chemical composition containing, on a mass percent basis,
C: 0.030% or more and 0.300% or less,
Si: 0.010% or more and 0.500% or less,
Mn: 0.30% or more and 2.50% or less,
P: 0.050% or less,
S: 0.0200% or less,
Al: 0.005% or more and 0.100% or less, and
N: 0.0100% or less,
the balance being Fe and incidental impurities,
a steel microstructure at a center of a wall thickness of the electric resistance welded steel pipe contains 70% or more and 98% or less by volume of ferrite and bainite in total,
the remainder being one or two or more selected from pearlite, martensite, and austenite,
has an average grain size of 15.0 μm or less, and
has a CP value of 0.090 or less as determined using the following formula (1), and
the base metal portion has a tensile strength of 400 MPa or more, and
the base metal portion has a yield ratio of 97% or less.

CP = (total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less than 20 μm)/(total length of high-angle grain boundaries) (1)

[5] The electric resistance welded steel pipe according to [4], further containing, in addition to the chemical composition, on a mass percent basis, one or two or more selected from

Nb: 0.100% or less,
V: 0.100% or less,
Ti: 0.150% or less,
Cr: 0.50% or less,
Mo: 0.50% or less,
Cu: 0.50% or less,
Ni: 0.50% or less,
Ca: 0.0050% or less,
B: 0.0050% or less,
Mg: 0.020% or less,

Zr: 0.020% or less, and
REM: 0.020% or less.

[6] The electric resistance welded steel pipe according to [4] or [5], wherein the logarithmic standard deviation of the equivalent plastic strain distribution after application of a 4.0% tensile strain in the base metal portion is 0.60 or less.
[7] A line pipe including the electric resistance welded steel pipe according to [4] or [5].
[8] A line pipe including the electric resistance welded steel pipe according to [6].
[9] A rectangular steel pipe including a flat portion and a corner portion,

wherein the rectangular steel pipe has a chemical composition containing, on a mass percent basis,
C: 0.030% or more and 0.300% or less,
Si: 0.010% or more and 0.500% or less,
Mn: 0.30% or more and 2.50% or less,
P: 0.050% or less,
S: 0.0200% or less,
Al: 0.005% or more and 0.100% or less, and
N: 0.0100% or less,
the balance being Fe and incidental impurities,
a steel microstructure at a center of a wall thickness of the rectangular steel pipe
contains 70% or more and 98% or less by volume of ferrite and bainite in total,
the remainder being one or two or more selected from pearlite, martensite, and austenite,
has an average grain size of 15.0 μm or less,
has a CP value of 0.090 or less as determined using the following formula (1),
the flat portion has a tensile strength of 400 MPa or more, and
the flat portion has a yield ratio of 97% or less.

CP = (total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less than 20 μm)/(total length of high-angle grain boundaries) (1)

[10] The rectangular steel pipe according to [9], further containing, in addition to the chemical composition, on a mass percent basis, one or two or more selected from

Nb: 0.100% or less,
V: 0.100% or less,
Ti: 0.150% or less,
Cr: 0.50% or less,
Mo: 0.50% or less,
Cu: 0.50% or less,
Ni: 0.50% or less,
Ca: 0.0050% or less,
B: 0.0050% or less,
Mg: 0.020% or less,
Zr: 0.020% or less, and
REM: 0.020% or less.

[11] The rectangular steel pipe according to [9] or [10], wherein the logarithmic standard deviation of the equivalent plastic strain distribution after application of a 4.0% tensile strain in the flat portion is 0.60 or less.
[12] A building structure including the rectangular steel pipe according to [9] or [10] as a column member.
[13] A building structure including the rectangular steel pipe according to [11] as a column member.

Advantageous Effects of Invention

[0016] The present invention can provide an electric resistance welded steel pipe or a rectangular steel pipe with high buckling resistance and a hot-rolled steel sheet used as a material thereof. The present invention can also provide a line pipe or a building structure using the electric resistance welded steel pipe or the rectangular steel pipe.

Brief Description of Drawings

[0017] [Fig. 1] Fig. 1 is a schematic view of a test piece for a tensile test used for measurement of an equivalent plastic strain distribution.

Description of Embodiments

[0018] The present invention is described in detail below.

[0019] A hot-rolled steel sheet according to the present invention has a chemical composition containing, on a mass percent basis, C: 0.030% or more and 0.300% or less, Si: 0.010% or more and 0.500% or less, Mn: 0.30% or more and 2.50% or less, P: 0.050% or less, S: 0.0200% or less, Al: 0.005% or more and 0.100% or less, and N: 0.0100% or less, with the balance being Fe and incidental impurities. A steel microstructure at the center of the sheet thickness of the hot-rolled steel sheet contains 70% or more and 98% or less by volume of ferrite and bainite in total, the remainder being one or two or more selected from pearlite, martensite, and austenite, has an average grain size of 15.0 μm or less, and has a CP value of 0.090 or less as determined using the following formula (1). Furthermore, the tensile strength is 400 MPa or more, and the yield ratio is 90% or less. Furthermore, the logarithmic standard deviation of the equivalent plastic strain distribution after application of an 8.0% tensile strain is preferably 0.70 or less.

CP = (total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less than 20 μm)/(total length of high-angle grain boundaries) (1)

[0020] An electric resistance welded steel pipe according to the present invention includes a base metal portion and an electric resistance weld and has a chemical composition containing, on a mass percent basis, C: 0.030% or more and 0.300% or less, Si: 0.010% or more and 0.500% or less, Mn: 0.30% or more and 2.50% or less, P: 0.050% or less, S: 0.0200% or less, Al: 0.005% or more and 0.100% or less, and N: 0.0100% or less, with the balance being Fe and incidental impurities. A steel microstructure at the center of the wall thickness of the elctric resistance welded steel pipe contains 70% or more and 98% or less by volume of ferrite and bainite in total, the remainder being one or two or more selected from pearlite, martensite, and austenite, has an average grain size of 15.0 μm or less, and has a CP value of 0.090 or less as determined using the formula (1). Furthermore, the base metal portion has a tensile strength of 400 MPa or more, and the base metal portion has a yield ratio of 97% or less. Furthermore, the logarithmic standard deviation of the equivalent plastic strain distribution after application of a 4.0% tensile strain in the base metal portion is preferably 0.60 or less.

[0021] A rectangular steel pipe according to the present invention includes a flat portion and a corner portion and has a chemical composition containing, on a mass percent basis, C: 0.030% or more and 0.300% or less, Si: 0.010% or more and 0.500% or less, Mn: 0.30% or more and 2.50% or less, P: 0.050% or less, S: 0.0200% or less, Al: 0.005% or more and 0.100% or less, and N: 0.0100% or less, with the balance being Fe and incidental impurities. A steel microstructure at the center of the wall thickness of the rectangular steel pipe contains 70% or more and 98% or less by volume of ferrite and bainite in total, the remainder being one or two or more selected from pearlite, martensite, and austenite, has an average grain size of 15.0 μm or less, and has a CP value of 0.090 or less as determined using the formula (1). Furthermore, the flat portion has a tensile strength of 400 MPa or more, and the flat portion has a yield ratio of 97% or less. Furthermore, the logarithmic standard deviation of the equivalent plastic strain distribution after application of a 4.0% tensile strain in the flat portion is preferably 0.60 or less.

[0022] First, the reasons for limiting the chemical compositions of the hot-rolled steel sheet, the electric resistance welded steel pipe, and the rectangular steel pipe in the present invention are described below. In the present description, unless otherwise specified, "%" of each component content refers to "% by mass".

C: 0.030% or more and 0.300% or less

[0023] C is an element that increases the strength of steel by solid-solution strengthening. C is an element that promotes the formation of pearlite, increases hardenability and thereby contributes to the formation of martensite, contributes to stabilization of austenite, and also contributes to the formation of a hard phase. To ensure the strength intended in the present invention, the C content needs to be 0.030% or more. However, a C content of more than 0.300% results in a high proportion of a hard phase, and the yield ratio intended in the present invention cannot be achieved. This also results in a nonuniform strain distribution during deformation when tensile strain is applied, and cannot achieve an appropriate logarithmic standard deviation of the equivalent plastic strain distribution intended in the present invention. Thus, the C content is 0.030% or more and 0.300% or less. The C content is preferably 0.035% or more, more preferably 0.040% or more. The C content is preferably 0.250% or less, more preferably 0.200% or less.

Si: 0.010% or more and 0.500% or less

[0024] Si is an element that increases the strength of steel by solid-solution strengthening. To produce such an effect, the Si content is preferably 0.010% or more. However, a Si content of more than 0.500% results in a higher proportion of a hard phase, and the yield ratio intended in the present invention cannot be achieved. This also results in a nonuniform strain distribution during deformation when tensile strain is applied, and cannot achieve an appropriate logarithmic standard deviation of the equivalent plastic strain distribution intended in the present invention. Thus, the Si content is 0.500% or less. The Si content is preferably 0.020% or more, more preferably 0.030% or more. The Si content is preferably 0.400% or less, more preferably 0.300% or less.

Mn: 0.30% or more and 2.50% or less

[0025] Mn is an element that increases the strength of steel by solid-solution strengthening. Mn is also an element that lowers the transformation start temperature and thereby contributes to refinement of the microstructure. To ensure the strength and microstructure intended in the present invention, the Mn content needs to be 0.30% or more. At a Mn content of more than 2.50%, however, the yield ratio intended in the present invention cannot be achieved. This also results in a nonuniform strain distribution during deformation when tensile strain is applied, and cannot achieve an appropriate logarithmic standard deviation of the equivalent plastic strain distribution intended in the present invention. Thus, the Mn content is 0.30% or more and 2.50% or less. The Mn content is preferably 0.40% or more, more preferably 0.50% or more. The Mn content is preferably 2.30% or less, more preferably 2.10% or less.

P: 0.050% or less

[0026] P segregates at a grain boundary, causes inhomogeneity of the material, and is preferably decreased as an incidental impurity as much as possible, but a P content of 0.050% or less is allowable. Thus, the P content is 0.050% or less. The P content is preferably 0.040% or less, more preferably 0.030% or less. Although the lower limit of the P content is not particularly specified, an excessive decrease results in a substantial increase in smelting cost, so that the P content is preferably 0.002% or more.

S: 0.0200% or less

[0027] S is typically present as MnS in steel, and MnS is thinly stretched in a hot rolling step and adversely affects ductility and toughness. Thus, in the present invention, S is preferably decreased as much as possible, but a S content of 0.0200% or less is allowable. Thus, the S content is 0.0200% or less. The S content is preferably 0.0150% or less, more preferably 0.0100% or less. Although the lower limit of the S content is not particularly specified, an excessive decrease results in a substantial increase in smelting cost, so that the S content is preferably 0.0002% or more.

Al: 0.005% or more and 0.100% or less

[0028] Al is an element that acts as a strong deoxidizing agent when added to molten steel. Such an effect requires an Al content of 0.005% or more. However, an Al content of more than 0.100% results in lower weldability, an increase in the number of alumina inclusions, and lower surface quality. Thus, the Al content is 0.005% or more and 0.100% or less. The Al content is preferably 0.010% or more, more preferably 0.020% or more. The Al content is preferably 0.080% or less, more preferably 0.060% or less.

N: 0.0100% or less

[0029] N is an incidental impurity and is an element that has an effect of firmly locking the movement of dislocation and increasing the yield ratio. In the present invention, although it is desirable to decrease N as an impurity as much as possible, a N content of 0.0100% or less is allowable. Thus, the N content is 0.0100% or less. The N content is preferably 0.0090% or less, more preferably 0.0080% or less. However, an excessive decrease results in an increase in smelting cost, and the N content is therefore preferably 0.0010% or more, more preferably 0.0015% or more.

[0030] The balance may be Fe and incidental impurities. The incidental impurities in the balance are, for example, Sn, As, Sb, Bi, Co, Pb, Zn, and O. 0.1% or less of Sn, 0.05% or less of As, Sb, or Co, and 0.005% or less of Bi, Pb, Zn, or O may be contained without losing the advantages of the present invention.

[0031] These components are basic chemical compositions of a hot-rolled steel sheet, an electric resistance welded steel pipe, and a rectangular steel pipe in the present invention. Although these essential elements can achieve characteristics intended in the present invention, when necessary, the following elements may be contained in the following content ranges.

[0032] One or two or more selected from Nb: 0.100% or less, V: 0.100% or less, Ti: 0.150% or less, Cr: 0.50% or less, Mo: 0.50% or less, Cu: 0.50% or less, Ni: 0.50% or less, Ca: 0.0050% or less, B: 0.0050% or less, Mg: 0.020% or less, Zr: 0.020% or less, and REM: 0.020% or less

Nb: 0.100% or less, V: 0.100% or less, Ti: 0.150% or less

[0033] Nb, Ti, and V are elements that form fine carbide or nitride in steel and contribute to an improvement in the strength of the steel through strengthening by a precipitate, and may be contained as required. Although the Nb, Ti, or V content may be 0%, when Nb, Ti, or V is contained, preferably, the Nb content is 0.001% or more, the Ti content is 0.001% or more, and the V content is 0.001% or more. More preferably, the Nb content is 0.008% or more, the V content is 0.008% or more, and the Ti content is 0.008% or more. On the other hand, an excessive content may result in an increase in yield ratio and an increase in the logarithmic standard deviation of the equivalent plastic strain distribution. Thus, when Nb, Ti, or V is contained, preferably, the Nb content is 0.100% or less, the V content is 0.100% or less, and the Ti content is 0.150% or less. More preferably, the Nb content is 0.070% or less, the V content is 0.070% or less, and the Ti content is 0.110% or less. When two or more selected from Nb, Ti, and V are contained, possibly due to an increase in yield ratio and an increase in the logarithmic standard deviation of the equivalent plastic strain distribution, the total amount (the total Nb + Ti + V content) is preferably 0.150% or less.

Cr: 0.50% or less, Mo: 0.50% or less

[0034] Cr and Mo are elements that increase the hardenability of steel and increase the strength of steel, and may be contained as required. Although the Cr or Mo content may be 0%, when Cr or Mo is contained, preferably, the Cr content is 0.01% or more, and the Mo content is 0.01% or more. More preferably, the Cr content is 0.10% or more, and the Mo content is 0.10% or more. On the other hand, an excessive content may result in an increase in yield ratio and an increase in the logarithmic standard deviation of the equivalent plastic strain distribution. Thus, when Cr or Mo is contained, preferably, the Cr content is 0.50% or less, and the Mo content is 0.50% or less. More preferably, the Cr content is 0.30% or less, and the Mo content is 0.30% or less.

Cu: 0.50% or less, Ni: 0.50% or less

[0035] Cu and Ni are elements that increase the strength of steel by solid-solution strengthening, and may be contained as required. Although the Cu or Ni content may be 0%, when Cu or Ni is contained, preferably, the Cu content is 0.01% or more, and the Ni content is 0.01% or more. More preferably, the Cu content is 0.10% or more, and the Ni content is 0.10% or more. On the other hand, an excessive content may result in an increase in yield ratio and an increase in the logarithmic standard deviation of the equivalent plastic strain distribution. Thus, when Cu or Ni is contained, preferably, the Cu content is 0.50% or less, and the Ni content is 0.50% or less. More preferably, the Cu content is 0.35% or less, and the Ni content is 0.35% or less.

Ca: 0.0050% or less

[0036] Ca is an element that spheroidizes a sulfide, such as MnS, that is thinly stretched in a hot rolling step and thereby contributes to improving the ductility and toughness of steel, and may be contained as required. Although the Ca content may be 0%, when Ca is contained, the Ca content is preferably 0.0002% or more. The Ca content is more preferably 0.0010% or more. However, a Ca content of more than 0.0050% may result in the formation of a Ca oxide cluster in steel and lower ductility and toughness. Thus, when Ca is contained, the Ca content is preferably 0.0050% or less. The Ca content is more preferably 0.0040% or less.

B: 0.0050% or less

[0037] B is an element that lowers the ferrite transformation start temperature and thereby contributes to refinement of the microstructure. Although the B content may be 0%, when B is contained, the B content is preferably 0.0001% or more. More preferably, the B content is 0.0005% or more. However, a B content of more than 0.0050% may result in an increase in yield ratio and an increase in the logarithmic standard deviation of the equivalent plastic strain distribution. Thus, when B is contained, the B content is preferably 0.0050% or less. The B content is more preferably 0.0040% or less.

Mg: 0.020% or less, Zr: 0.020% or less, REM: 0.020% or less

[0038] Mg, Zr, and REM are elements that increase the strength of steel through grain refinement, and may be contained as required. Although the Mg, Zr, or REM content may be 0%, when Mg, Zr, or REM is contained, preferably, the Mg content is 0.0005% or more, the Zr content is 0.0005% or more, and the REM content is 0.0005% or more. On the other hand, an excessive content may result in an increase in yield ratio and an increase in the logarithmic standard deviation of the equivalent plastic strain distribution. Thus, when Mg, Zr, or REM is contained, preferably, the Mg content is 0.020% or less, the Zr content is 0.020% or less, and the REM content is 0.020% or less. More preferably, the Mg content is 0.010% or less, the Zr content is 0.010% or less, and the REM content is 0.010% or less. REM is a general term for a total of 17 elements of Sc, Y, and lanthanoid elements. One or more of these 17 elements can be contained in steel, and the REM content means the total content of these elements.

[0039] Next, the reasons for limiting the steel microstructure of a hot-rolled steel sheet, an electric resistance welded steel pipe, or a rectangular steel pipe in the present invention are described. Furthermore, a limited steel microstructure described later is a steel microstructure at the center of the sheet thickness or at the center of the wall thickness and is present at a thickness 1/2t position. In the present invention, the thickness 1/2t position means a position of half (the center of) the thickness t in the sheet thickness direction.

Total volume fraction of ferrite and bainite: 70% or more and 98% or less

[0040] Ferrite and bainite are soft microstructures and can be mixed with another hard microstructure to decrease the yield ratio. To achieve the low yield ratio intended in the present invention by such an effect, the total volume fraction of ferrite and bainite needs to be 70% or more.

[0041] The total volume fraction of ferrite and bainite is preferably 75% or more, more preferably 80% or more. When the total volume fraction of ferrite and bainite is more than 98%, however, the tensile strength intended in the present invention cannot be achieved, so that the total volume fraction of ferrite and bainite needs to be 98% or less. The total volume fraction of ferrite and bainite is preferably 97% or less, more preferably 95% or less.

Remainder: one or two or more selected from pearlite, martensite, and austenite

[0042] Pearlite, martensite, and austenite are hard microstructures, particularly increase the strength of steel, and can be mixed with soft ferrite to achieve a low yield ratio. To produce such an effect, the remainder other than ferrite and bainite is one or two or more selected from pearlite, martensite, and austenite. The total volume fraction of pearlite, martensite, and austenite is 2% or more and 30% or less. The total volume fraction is preferably 3% or more, more preferably 5% or more. The total volume fraction is preferably 25% or less, more preferably 20% or less.

[0043] The volume fractions of ferrite, bainite, pearlite, martensite, and austenite can be measured by a method described later in Examples.

Average grain size: 15.0 μm or less

[0044] When crystal grains have an average grain size of more than 15.0 μm, the tensile strength intended in the present invention cannot be achieved. Furthermore, an appropriate logarithmic standard deviation of the equivalent plastic strain distribution intended in the present invention cannot be achieved. This is because, when the average grain size is large, the connectivity between coarse grains increases, strains generated in the coarse grains during deformation are connected to each other, and the strain distribution becomes more nonuniform as the deformation proceeds. Thus, the crystal grains have an average grain size of 15.0 μm or less. The crystal grains preferably have an average grain size of 13.0 μm or less, more preferably 10.0 μm or less. A small average grain size results in a high yield ratio, so that the average grain size is preferably 2.0 μm or more. The average grain size is more preferably 3.0 μm or more.

CP value: 0.090 or less

[0045] The CP value is a numerical value representing the connectivity between coarse grains with a grain size of 20 μm or more and is determined using the following formula (1). A high CP value results in a high proportion of grain boundaries between coarse crystal grains and more coarse grains connected to each other. When the CP value is more than 0.090, strains generated in coarse grains during deformation are connected to each other, and the strain distribution becomes more nonuniform as the deformation proceeds, so that an appropriate logarithmic standard deviation of the equivalent plastic strain distribution intended in the present invention cannot be achieved. Thus, the CP value is 0.090 or less. The CP value is preferably 0.080 or less, more preferably 0.070 or less. Although the CP value is preferably as small as possible and has no particular lower limit, an excessive decrease results in an increase in production costs and production load, so that the CP value is preferably 0.001 or more.

$$CP = \text{(total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less than 20 } \mu\text{m)/(total length of high-angle grain boundaries)} \quad (1)$$

The "total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less than 20 μm" in the formula (1) is the total length of high-angle grain boundaries in a portion where crystal grains with a grain size of 20 μm or more are adjacent to each other.

[0046] The average grain size and the CP value can be measured by a SEM/EBSD method and herein can be measured by a method described later in Examples.

[0047] Next, the reasons for limiting characteristics in a tensile test of a hot-rolled steel sheet, an electric resistance welded steel pipe, or a rectangular steel pipe in the present invention are described.

Tensile strength of hot-rolled steel sheet: 400 MPa or more

[0048] When a hot-rolled steel sheet has a tensile strength of less than 400 MPa, the tensile strength of an electric resistance welded steel pipe and the tensile strength of a rectangular steel pipe intended in the present invention cannot be achieved. Thus, a hot-rolled steel sheet has a tensile strength of 400 MPa or more. A hot-rolled steel sheet preferably has a tensile strength of 420 MPa or more, more preferably 450 MPa or more. Although the upper limit of the tensile strength of a hot-rolled steel sheet is not particularly limited, the tensile strength of the hot-rolled steel sheet is, for example, 700 MPa or less.

Yield ratio of hot-rolled steel sheet: 90% or less

[0049] When a hot-rolled steel sheet has a yield ratio of more than 90%, the yield ratio of an electric resistance welded steel pipe and the yield ratio of a rectangular steel pipe intended in the present invention cannot be achieved. Thus, a hot-rolled steel sheet has a yield ratio of 90% or less. A hot-rolled steel sheet preferably has a yield ratio of 88% or less, more preferably 85% or less. Although the lower limit of the yield ratio of a hot-rolled steel sheet is not particularly limited, the yield ratio of the hot-rolled steel sheet is, for example, 60% or more.

[0050] Logarithmic standard deviation of equivalent plastic strain distribution after application of 8.0% tensile strain to hot-rolled steel sheet: 0.70 or less

[0051] The equivalent plastic strain distribution can be approximated by a logarithmic normal distribution with the horizontal axis representing the equivalent plastic strain (unit: none) and the vertical axis representing the fraction (area fraction) (unit: %). In the logarithmic normal distribution, the logarithm of a variable (horizontal axis) follows a normal distribution. Thus, it can be approximated by a normal distribution on the assumption that the horizontal axis represents the natural logarithm of the equivalent plastic strain (unit: none) and the vertical axis represents the fraction (area fraction) (unit: %). In the present invention, the standard deviation at this time is defined as the "logarithmic standard deviation". As the logarithmic standard deviation decreases, a peak of the equivalent plastic strain distribution becomes sharper, and the plastic strain distribution becomes more uniform.

[0052] When the logarithmic standard deviation of an equivalent plastic strain distribution after application of an 8.0% tensile strain to a hot-rolled steel sheet is 0.70 or less, it is easier to achieve an appropriate logarithmic standard deviation of an equivalent plastic strain distribution of an electric resistance welded steel pipe and an appropriate logarithmic standard deviation of an equivalent plastic strain distribution of a rectangular steel pipe intended in the present invention. Thus, the logarithmic standard deviation after application of an 8.0% tensile strain to a hot-rolled steel sheet is preferably 0.70 or less. The logarithmic standard deviation is more preferably 0.68 or less, still more preferably 0.65 or less. Although the logarithmic standard deviation is preferably as small as possible and has no particular lower limit, an excessive decrease results in an increase in production costs and production load, so that the logarithmic standard deviation is preferably 0.050 or more.

[0053] Tensile strength of base metal portion of electric resistance welded steel pipe and tensile strength of flat portion of rectangular steel pipe: 400 MPa or more

[0054] When the tensile strength of a base metal portion of an electric resistance welded steel pipe and the tensile strength of a flat portion of a rectangular steel pipe are less than 400 MPa, the buckling resistance decreases. Thus, the tensile strength is 400 MPa or more. The tensile strength is preferably 420 MPa or more, more preferably 450 MPa or more. Although the upper limit of the tensile strength is not particularly limited, the tensile strength is, for example, 700 MPa or less.

[0055] Yield ratio of base metal portion of electric resistance welded steel pipe and yield ratio of flat portion of rectangular steel pipe: 97% or less

[0056] When the yield ratio of a base metal portion of an electric resistance welded steel pipe and the yield ratio of a flat portion of a rectangular steel pipe are more than 97%, the buckling resistance decreases. Thus, the yield ratio is 97% or less. The yield ratio is preferably 96% or less, more preferably 95% or less. Although the lower limit of the yield ratio is not particularly limited, the yield ratio is, for example, 75% or more.

[0057] Logarithmic standard deviation of equivalent plastic strain distribution after application of 4.0% tensile strain in base metal portion of electric resistance welded steel pipe and flat portion of rectangular steel pipe: 0.60 or less

[0058] When the logarithmic standard deviation of an equivalent plastic strain distribution after application of a 4.0% tensile strain in a base metal portion of an electric resistance welded steel pipe and a flat portion of a rectangular steel pipe is 0.60 or less, buckling resistance is more likely to be improved. Thus, the logarithmic standard deviation is preferably 0.60 or less. The logarithmic standard deviation is more preferably 0.58 or less, still more preferably 0.55 or less. Although the logarithmic standard deviation is preferably as small as possible and has no particular lower limit, an excessive decrease results in an increase in production costs and production load, so that the logarithmic standard deviation is preferably 0.050 or more.

[0059] The tensile strength and the yield ratio can be measured in a tensile test described later in Examples. Furthermore, the logarithmic standard deviation of an equivalent plastic strain distribution can be measured by combining a tensile test and a SEM-DIC method described later in Examples. More specifically, the logarithmic standard deviation of an equivalent plastic strain distribution can be determined by a method described later in Examples.

[0060] Next, a method for producing a hot-rolled steel sheet, an electric resistance welded steel pipe, or a rectangular steel pipe according to an embodiment of the present invention is described.

[0061] A hot-rolled steel sheet according to the present invention can be produced, for example, by performing a heating step of heating a steel material with the above-described chemical composition to a heating temperature of 1100°C or more and 1300°C or less, then performing a hot rolling step of rolling the steel material at a finish rolling delivery temperature of 750°C or more and 850°C or less and at an average cooling rate of 1.0°C/s or more in the temperature range of 900°C or more in terms of the temperature at the center of the sheet thickness to produce a hot-rolled sheet, after the hot rolling step, performing a cooling step of cooling the hot-rolled sheet at an average cooling rate of 5°C/s or more and 50°C/s or less from the start of cooling to the stop of cooling in terms of the temperature at the center of the sheet thickness and at a cooling stop temperature of 400°C or more and 650°C or less, and after the cooling step performing a coiling step of coiling the hot-rolled sheet.

[0062] Furthermore, an electric resistance welded steel pipe according to the present invention is produced by forming the hot-rolled steel sheet into a cylindrical shape by cold roll forming, butt-welding both circumferential end portions of the cylindrical shape by electric resistance welding, and then adjusting the outer diameter and the roundness by cold forming using a roll with a perfect circular hole shape.

[0063] A rectangular steel pipe according to the present invention is produced by forming the hot-rolled steel sheet into a cylindrical shape by cold roll forming, butt-welding both circumferential end portions of the cylindrical shape by electric resistance welding, and then forming a flat portion and a corner portion by cold forming using a roll with a target polygonal hole shape. A rectangular steel pipe according to the present invention includes a regular polygon (equilateral triangle, square, regular pentagon, or the like), an equilateral polygon with a combination of different interior angles (rhombus, star, or the like), and a polygon with a combination of different side lengths (isosceles triangle, rectangle, parallelogram, trapezoid, or the like). When a rectangular steel pipe according to the present invention is used as a column member of a building, since beams are usually joined to four sides at intervals of 90 degrees, the rectangular steel pipe preferably has a square or rectangular cross section.

[0064] The term "cylindrical shape" means that the cross section of the pipe has a "C" shape. In the following description of the production method, unless otherwise specified, the temperature expressed in "°C" is the surface temperature of a steel material or a steel sheet (hot-rolled sheet). The surface temperature can be measured with a radiation thermometer or the like. The temperature at the center of the sheet thickness of a steel sheet can be determined by calculating the temperature distribution in a cross section of the steel sheet by heat transfer analysis and correcting the result by the surface temperature of the steel sheet.

[0065] In the present invention, a steel material (steel slab) can be melted by any method, for example, by a known melting method using a converter, an electric arc furnace, a vacuum melting furnace, or the like. Any casting method may be used, and a desired size is obtained by a known casting method, such as a continuous casting method. Instead of the continuous casting method, an ingot casting and blooming method may be applied without any problem. Molten steel may be further subjected to secondary refining, such as ladle refining.

[0066] A steel material (steel slab) thus produced is then heated to a heating temperature of 1100°C or more and 1300°C or less and is then subjected to a hot rolling step at a finish rolling delivery temperature of 750°C or more and 850°C or less and at an average cooling rate of 1.0°C/s or more in the temperature range of 900°C or more in terms of the temperature at the center of the sheet thickness to produce a hot-rolled sheet.

Heating temperature: 1100°C or more and 1300°C or less

[0067] When the heating temperature is less than 1100°C, a material to be rolled (steel slab) has large deformation resistance and is difficult to be rolled. On the other hand, when the heating temperature is more than 1300°C, austenite grains are coarsened, fine austenite grains cannot be formed in the subsequent rolling (rough rolling, finish rolling), and it is difficult to ensure the average grain size intended in the present invention. Furthermore, it is difficult to suppress the formation of coarse grains, and it is difficult to control the CP value in the target range of the present invention. Thus, the heating temperature in a furnace before hot rolling is 1100°C or more and 1300°C or less. The heating temperature is more preferably 1120°C or more. The heating temperature is more preferably 1280°C or less.

[0068] In the present invention, after a steel slab is produced, the steel slab may be temporarily cooled to room temperature and then reheated by a known method. Alternatively, without being cooled to room temperature, a steel slab may be subjected without problems to an energy-saving process, such as hot direct rolling, in which a hot slab is charged directly into a furnace or is immediately rolled after slight heat retention.

Finish rolling delivery temperature: 750°C or more and 850°C or less

[0069] When the finish rolling delivery temperature is less than 750°C, the steel sheet surface temperature becomes equal to or lower than the ferrite transformation start temperature during finish rolling, and ferrite is formed and becomes deformed ferrite grains elongated in the rolling direction by subsequent rolling, which causes an increase in yield ratio. On the other hand, when the finish rolling delivery temperature is more than 850°C, the rolling reduction in an austenite non-recrystallization temperature range is insufficient, fine austenite grains cannot be formed, and it is difficult to ensure the average grain size intended in the present invention. Furthermore, it is difficult to suppress the formation of coarse grains, and it is difficult to control the CP value in the target range of the present invention. Thus, the finish rolling delivery temperature is 750°C or more and 850°C or less. The finish rolling delivery temperature is more preferably 760°C or more. The finish rolling delivery temperature is more preferably 840°C or less.

[0070] Average cooling rate in the temperature range of 900°C or more in terms of the temperature at the center of the sheet thickness: 1.0°C/s or more

[0071] In the present invention, the average cooling rate in the temperature range of 900°C or more in terms of the temperature at the center of the sheet thickness (hereinafter sometimes referred to as the average cooling rate in hot rolling) can be increased to suppress coarsening of austenite in an austenite recrystallization temperature range and achieve the average grain size and the CP value intended in the present invention. To achieve the average cooling rate, for example, a material to be rolled may be cooled using water cooling equipment during rolling. When the average cooling rate is less than 1.0°C/s, austenite is coarsened in the austenite recrystallization temperature range, and it is difficult to ensure the average grain size intended in the present invention. Furthermore, it is difficult to suppress the formation of coarse grains, and it is difficult to control the CP value in the target range of the present invention. The average cooling rate is preferably 1.2°C/s or more, more preferably 1.5°C/s or more. Since the equipment load increases at an average cooling rate of more than 5.0°C/s, the average cooling rate is preferably 5.0°C/s or less.

[0072] The average cooling rate in the temperature range of 900°C or more in terms of the temperature at the center of the sheet thickness is determined as the average cooling rate at the center of the sheet thickness from when a steel material (steel slab) is extracted from a furnace to when the temperature at the center of the sheet thickness reaches 900°C. That is, the average cooling rate is determined by [(the temperature at the center of the sheet thickness (°C) when a steel material is extracted from a furnace - 900 (°C))/the time (s) from when the steel material is extracted from the furnace to when the temperature at the center of the sheet thickness of the steel material reaches 900°C].

[0073] In the present invention, the upper limit of the finished sheet thickness is preferably, but not limited to, 32 mm or less from the perspective of ensuring the required cooling rate and controlling the steel sheet temperature. Although the lower limit of the finished sheet thickness is also not particularly limited, the sheet thickness is, for example, 5 mm or more.

[0074] After the hot rolling step, the hot-rolled sheet is subjected to a cooling step. In the cooling step, cooling is performed at an average cooling rate of 5°C/s or more and 50°C/s or less from the start of cooling to the stop of cooling and at a cooling stop temperature of 400°C or more and 650°C or less.

Average cooling rate from start of cooling to stop of cooling (end of cooling): 5°C/s or more and 50°C/s or less

[0075] When the average cooling rate in the temperature range from the start of cooling to the stop of cooling described later in terms of the temperature at the center of the sheet thickness of the hot-rolled sheet (hereinafter sometimes referred to as the average cooling rate in the cooling step) is less than 5°C/s, the nucleation frequency of ferrite decreases, and ferrite grains are coarsened, so that it is difficult to ensure the average grain size intended in the present invention. Furthermore, it is difficult to suppress the formation of coarse grains, and it is difficult to control the CP value in the target range of the present invention. On the other hand, when the average cooling rate is more than 50°C/s, a large amount of martensite is formed, and the total volume fraction of ferrite and bainite intended in the present invention cannot be achieved. The average cooling rate is preferably 7°C/s or more, more preferably 10°C/s or more. The average cooling rate is preferably 45°C/s or less, more preferably 40°C/s or less. In the cooling step, an intentional cooling start time point of water cooling or the like is defined as the start of cooling, and natural cooling before that is not included in the cooling.

[0076] In the present invention, from the perspective of suppressing the formation of ferrite on the steel sheet surface before cooling, cooling is preferably started immediately after completion of finish rolling.

Cooling stop temperature: 400°C to 650°C

[0077] When the cooling stop temperature is less than 400°C in terms of the temperature at the center of the sheet thickness of the hot-rolled sheet, a large amount of martensite is formed, and the total volume fraction of ferrite and bainite intended in the present invention cannot be achieved. On the other hand, when the cooling stop temperature is more than 650°C, the nucleation frequency of ferrite decreases, and the ferrite grains are coarsened, so that it is difficult to ensure the average grain size intended in the present invention. Furthermore, it is difficult to suppress the formation of coarse grains, and it is difficult to control the CP value in the target range of the present invention. The cooling stop temperature is preferably 420°C or more, more preferably 450°C or more. The cooling stop temperature is preferably 620°C or less, more preferably 600°C or less.

[0078] In the present invention, unless otherwise specified, the average cooling rate in the cooling step is a value determined by ((the temperature at the center of the sheet thickness of the hot-rolled sheet before cooling - the temperature at the center of the sheet thickness of the hot-rolled sheet after cooling)/cooling time). The cooling method may be water cooling, such as injection of water from a nozzle, cooling by injection of a coolant gas, or the like. In the present invention, a cooling operation (treatment) is preferably performed on both sides of the hot-rolled sheet so that both sides of the hot-rolled sheet are cooled under the same conditions.

[0079] The cooling step is followed by a coiling step of coiling the hot-rolled sheet and then naturally cooling the hot-rolled sheet.

[0080] Thus, a hot-rolled steel sheet according to the present invention is produced. A hot-rolled steel sheet according to the present invention has a tensile strength of 400 MPa or more and a yield ratio of 90% or less. Furthermore, the logarithmic standard deviation of an equivalent plastic strain distribution after application of an 8.0% tensile strain can be 0.70 or less.

[0081] Furthermore, an electric resistance welded steel pipe or a rectangular steel pipe produced using the hot-rolled steel sheet as a material has a tensile strength of 400 MPa or more and a yield ratio of 97% or less. Furthermore, the logarithmic standard deviation of an equivalent plastic strain distribution after application of a 4.0% tensile strain can be 0.60 or less. An electric resistance welded steel pipe or a rectangular steel pipe according to the present invention has high buckling resistance.

[0082] Furthermore, a line pipe or a building structure using the electric resistance welded steel pipe or the rectangular steel pipe can have high buckling resistance. Thus, the building structure has high buckling resistance, can withstand an external load, and is therefore suitable for use as a column member of a building structure.

EXAMPLES

[0083] The present invention is described in more detail in the following examples. The present invention is not limited to these examples.

[0084] A steel material (steel slab) with a chemical composition shown in Table 1 was melted and subjected to a heating step, a hot rolling step, and a cooling step under the conditions shown in Table 2 to produce a hot-rolled steel sheet with a finished sheet thickness (mm) shown in Table 2.

[Table 1]

No	Chemical composition (% by mass)																	
	C	Si	Mn	P	S	Al	N	Nb	V	Ti	Cr	Mo	Cu	Ni	Ca	B	Mg	Zr	REM
1	0.034	0.173	1.25	0.004	0.0008	0.033	0.0041	0.021	0.049	0.022	-	0.12	0.15	0.14	0.0033	-	-	-	-
2	0.045	0.172	0.96	0.005	0.0006	0.032	0.0032	0.024	0.031	0.053	-	-	0.21	0.13	0.0018	-	-	0.013	-
3	0.288	0.038	0.34	0.010	0.0071	0.029	0.0038	0.073	-	0.015	0.36	0.34	-	-	-	-	0.011	-	0.007
4	0.143	0.484	2.49	0.006	0.0022	0.030	0.0044	-	-	-	-	-	-	-	-	-	-	-	-
5	0.171	0.249	0.88	0.035	0.0045	0.025	0.0024	0.031	-	0.009	-	-	-	-	-	0.0037	-	-	0.016
6	0.060	0.120	1.18	0.022	0.0118	0.026	0.0030	0.019	0.027	0.020	0.21	0.28	-	-	-	-	-	-	-
7	<u>0.025</u>	0.091	1.22	0.008	0.0007	0.044	0.0037	0.018	-	0.025	-	-	-	-	-	-	-	-	-
8	<u>0.312</u>	0.272	1.82	0.009	0.0004	0.035	0.0029	0.050	-	0.014	-	-	0.11	0.22	-	-	-	-	-
9	0.115	<u>0.008</u>	<u>0.27</u>	0.018	0.0024	0.038	0.0035	-	-	0.049	-	-	0.14	0.16	-	-	-	-	-
10	0.076	<u>0.553</u>	<u>2.60</u>	0.020	0.0011	0.025	0.0041	-	-	0.037	-	-	-	-	-	-	-	-	-
11	0.166	0.247	0.84	0.029	0.0043	0.022	0.0032	0.035	-	0.010	-	-	-	-	-	-	-	-	-
12	0.039	0.178	1.19	0.006	0.0004	0.031	0.0036	0.020	0.032	0.018	0.15	-	-	-	-	-	-	-	-

- The chemical composition other than the above contains residual Fe and incidental impurities.
- The underlined values are outside the scope of the present invention.

[Table 2]

No	Heating step	Hot rolling step		Cooling step		Finished sheet thickness (mm)
	Heating temperature (°C)	Finish rolling delivery temperature (°C)	Average cooling rate in temperature range of 900°C or more (°C/s)	Cooling stop temperature (°C)	Average cooling rate in cooling step (°C/s)	
1	1250	800	2.3	530	41	25
2	1200	820	1.5	520	46	22
3	1200	780	1.2	620	8	9
4	1280	810	1.9	500	34	25
5	1150	840	3.0	560	17	25
6	1130	770	1.3	570	26	21
7	1200	790	1.8	610	10	15
8	1150	800	1.1	540	29	22
9	1240	790	1.7	590	13	20
10	1260	860	2.4	490	43	22
11	1250	820	0.7	630	8	22
12	1200	850	1.9	680	9	19

[0085] The hot-rolled steel sheet thus produced was formed into a cylindrical open pipe (round steel pipe) by cold roll forming, and butt portions of the open pipe were electric-resistance-welded to produce a steel pipe material. The steel pipe material was then formed by rolls arranged vertically and horizontally to produce an electric resistance welded steel pipe with an outer diameter D (mm) and a wall thickness t (mm) or a rectangular steel pipe with a side length B (mm) and a wall thickness t (mm) shown in Table 3. The rectangular steel pipe has a square cross section.

[Table 3]

No	Steel pipe type	Dimensions of steel pipe	
		Outer diameter D or side length B (mm)	Wall thickness t (mm)
1	Electric resistance welded steel pipe	600	25
2	Rectangular steel pipe	400	22
3	Electric resistance welded steel pipe	150	9
4	Rectangular steel pipe	450	25
5	Rectangular steel pipe	500	25
6	Electric resistance welded steel pipe	400	21
7	Electric resistance welded steel pipe	500	15
8	Electric resistance welded steel pipe	400	22
9	Rectangular steel pipe	500	20
10	Electric resistance welded steel pipe	400	22
11	Rectangular steel pipe	400	22
12	Electric resistance welded steel pipe	400	19

[0086] A test specimen was taken from the hot-rolled steel sheet, the electric resistance welded steel pipe, or the rectangular steel pipe thus produced, and microstructure observation, a tensile test, and measurement of an equivalent plastic strain distribution described below were performed.

[Microstructure Observation]

[0087] A test specimen for microstructure observation was taken such that the observation surface was a cross section in the rolling direction during hot rolling and was located at a thickness 1/2t position, and the test specimen was polished and then subjected to nital etching. In the microstructure observation, the microstructure at a thickness 1/2t position of a steel sheet was observed and imaged using an optical microscope (magnification: 1000 times) or a scanning electron microscope (SEM, magnification: 1000 times). From an optical microscope image or a SEM image thus taken, the area fractions of ferrite, bainite, and remaining microstructures (pearlite, martensite, and austenite) were determined. The area fraction of each microstructure was calculated as an average value of values observed in five visual fields. The area fraction determined by the microstructure observation was defined as the volume fraction of each microstructure.

[0088] Ferrite is a product of diffusional transformation and has a microstructure with a low dislocation density and almost recovered. This includes polygonal ferrite and quasi-polygonal ferrite. Bainite is a two-phase microstructure of cementite and lath-shaped ferrite with a high dislocation density. Pearlite is a microstructure with layered cementite and ferrite. Austenite has no cement compared with bainite. Martensite and austenite were distinguished from bainite due to high contrast in the SEM image.

[0089] Since martensite and austenite in the optical microscope image and the SEM image were difficult to distinguish, the volume fraction of martensite was determined by measuring the area fraction of a microstructure observed as martensite or austenite from the SEM image and subtracting the volume fraction of austenite measured by a method described later from the area fraction.

[0090] The volume fraction of austenite was measured by X-ray diffraction. A test specimen for microstructure observation was prepared by grinding the steel sheet so that the diffraction plane was located at a thickness 1/2t position of the steel sheet, and then removing a worked surface layer by chemical polishing. A Kα ray of Mo was used for the measurement, and the volume fraction of austenite was determined from the integrated intensities for (200), (220), and (311) planes of fcc iron and (200) and (211) planes of bcc iron.

[0091] The average grain size and the CP value were measured by a SEM/EBSD method. The measurement region was 500 μm x 500 μm, and the measurement step size was 0.5 μm. On the basis of the resulting EBSD data, crystal orientation analysis software OIM Analysis (trademark) was used to obtain a grain boundary distribution using a boundary with an orientation difference of 15 degrees or more as a crystal grain boundary (high-angle grain boundary). The average grain size was determined as an arithmetic mean of equivalent circular diameters (grain sizes) of crystal grains. The CP value was obtained by calculating the total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less than 20 μm and the total length of high-angle grain boundaries and calculating the ratio thereof. The total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less than 20 μm is the sum total of the lengths of high-angle grain boundaries measured in the region excluding crystal grains with a grain size of less than 20 μm from the grain boundary distribution in the measurement region, and the total length of high-angle grain boundaries is the sum total of the lengths of high-angle grain boundaries measured from the grain boundary distribution in the measurement region. In the calculation of the average grain size and the CP value, crystal grains with a grain size of 2.0 μm or less were excluded as measurement noise.

[Tensile Test]

[0092] A JIS No. 5 test piece for tensile test was taken such that the tensile direction was parallel to the rolling direction. The test piece for tensile test was taken from a 1/4W (W: sheet width) position in the width direction from a widthwise end portion for a hot-rolled steel sheet, was taken from a position separated by 90 degrees in the circumferential direction from an electric resistance weld for an electric resistance welded steel pipe, and was taken from a flat portion adjacent to a flat portion including an electric resistance weld for a rectangular steel pipe. The tensile test was performed in accordance with the provisions of JIS Z 2241 (2011), and the yield stress σy and the tensile strength were measured to calculate the yield ratio defined by (yield stress σy)/(tensile strength).

[Equivalent Plastic Strain Distribution]

[0093] The equivalent plastic strain distribution was measured by the SEM-DIC method. A test piece for tensile test illustrated in Fig. 1 was taken from the center of the sheet thickness of a hot-rolled steel sheet, the center of the wall thickness of an electric resistance welded steel pipe, or the center of the wall thickness of a rectangular steel pipe such that the tensile direction was parallel to the rolling direction. With respect to the sheet width direction of a hot-rolled steel sheet, sampling was performed at 1/4W (W: sheet width) in the width direction from a widthwise end portion. With respect to the circumferential direction of an electric resistance welded steel pipe, sampling was performed at a position separated by 90 degrees in the circumferential direction from an electric resistance weld. With respect to a rectangular steel pipe, sampling was performed at a flat portion adjacent to a flat portion including an electric resistance weld. One surface of the test piece for tensile test was polished and etched with nital, and a parallel portion (tensile deformation portion) was imaged in five visual fields using a SEM (magnification: 1000 times). An 8.0% tensile strain was then applied to a test specimen taken from a hot-rolled steel sheet and a 4.0% tensile strain was applied to a test specimen taken from each of an electric resistance welded steel pipe and a rectangular steel pipe at a crosshead speed of 5 mm/min, and the load was removed. An image of the same visual field as that before stretching (before application of tensile strain) was then taken with the SEM (magnification: 1000 times). On the basis of SEM images thus taken before and after the stretching, the equivalent plastic strain distribution of an imaging plane was calculated by a DIC method using image analysis software GOM Correlate (available from GOM). The DIC method is a method of measuring a displacement or a strain at each portion of an observation surface by comparing a random pattern of an object surface before and after deformation. More specifically, a rectangular region called a subset is defined in an image before deformation, and the subset is tracked before and after deformation based on a random pattern inside the subset to calculate the displacement of the subset center point. This operation is exhaustively performed on the entire image to obtain a displacement distribution and a strain distribution. In the present invention, a nital etching mark of a metallic microstructure was used as a random pattern, and for an image of 1910 pixels x 2560 pixels the subset size was 80 pixels x 80 pixels (3.6 μm x 3.6 μm), and the measurement interval was 10 pixels (0.45 μm). One with the horizontal axis representing the natural logarithm of the obtained equivalent plastic strain (unit: none) and the vertical axis representing the fraction (area fraction) (unit: %) was approximated by a normal distribution, and the standard deviation at this time was taken as the logarithmic standard deviation (the logarithmic standard deviation of an equivalent plastic strain distribution). More specifically, the logarithmic standard deviation was determined by the following method. First, in the equivalent plastic strain range of 0 to 0.20, the fraction (area fraction) (unit: %) of each class was determined at a class width of 0.02. At this time, a class with an equivalent plastic strain of 0 or more and less than 0.02 was defined as a first class, a class with an equivalent plastic strain of 0.02 or more and less than 0.04 was defined as a second class, ..., and a class with an equivalent plastic strain of 0.18 or more and less than 0.20 was defined as a tenth class. With x_i as the natural logarithm of the class mark of an i-th class and x_0 as the average value of the natural logarithm of the equivalent plastic strain, the logarithmic standard deviation was determined using the formulae (4) and (5) below.

[Math. 1]

[0094]

$$\text{Logarithmic standard deviation} = \sqrt{\frac{1}{100}\sum_{i=1}^{10}\left[(x_i - x_0)^2 \times (\text{Fraction of i} - \text{th class})\right]} \quad \cdots (4)$$

[Math. 2]

[0095]

$$x_0 = \frac{1}{100}\sum_{i=1}^{10}\left[(x_i \times (\text{Fraction of i} - \text{th class})\right] \quad \cdots (5)$$

[Axial Compression Test]

[0096] A pressure-resistant plate was attached to both ends of an electric resistance welded steel pipe and a rectangular steel pipe, and an axial compression test was performed with a large compression testing machine. The stress at the maximum compressive load was defined as the maximum stress intensity σmax (N/mm^2). The yield stress σy determined in the tensile test was used to calculate the proof strength increase rate τ (= σmax/σy).

[0097] Table 4 shows the results for the hot-rolled steel sheets.

[Table 4]

No	Steel microstructure of hot-rolled steel sheet						Mechanical properties of hot-rolled steel sheet			Notes
	F fraction (%)	B fraction (%)	F+B fraction (%)	Remaining microstructure	Average grain size (μm)	CP	Tensile strength (MPa)	Yield ratio (%)	Logarithmic standard deviation	
1	2	96	98	M	4.7	0.053	604	83.3	0.58	Inventive example
2	6	91	97	M	4.2	0.043	593	80.2	0.60	Inventive example
3	65	8	73	P,M,A	13.5	0.070	419	75.9	0.52	Inventive example
4	33	49	82	P	8.4	0.021	568	75.0	0.34	Inventive example
5	47	44	91	P	5.1	0.027	559	78.5	0.41	Inventive example
6	28	58	86	P	7.3	0.061	527	81.4	0.55	Inventive example
7	86	10	96	M	12.4	0.034	384	71.7	0.54	Comparative example
8	17	49	66	P,M	5.2	0.068	613	91.2	0.73	Comparative example
9	83	16	99	P	15.3	0.032	365	70.6	0.41	Comparative example
10	12	53	65	P,M	5.9	0.045	589	90.8	0.76	Comparative example
11	90	0	90	P	15.7	0.093	377	73.3	0.80	Comparative example
12	84	9	93	M	8.6	0.097	491	72.4	0.81	Comparative example

- F fraction denotes the volume fraction of bainite, B fraction denotes the volume fraction of bainite, F+B fraction denotes the volume fraction of ferrite and bainite in total.
- In Remaining microstructure, P: pearlite, M: martensite, A: austenite.
- Underlined values are outside the scope of the present invention.

[0098] Table 5 shows the results for the electric resistance welded steel pipes and the rectangular steel pipes.

[Table 5]

No	Steel pipe type	Steel microstructure						Mechanical properties				Axial compressibility of steel pipe			Notes
		F fraction (%)	B fraction (%)	F+B fraction (%)	Remaining microstructure	Average grain size (μm)	CP	Yield stress σy (MPa)	Tensile strength (MPa)	Yield ratio (%)	Logarithmic standard deviation	Maximum stress intensity σmax (MPa)	Proof strength increase rate τ	Necessary lower limit of τ	
1	Electric resistance welded steel pipe	3	93	96	M	4.7	0.050	577	630	91.6	0.46	640	1.11	1.02	Inventive example
2	Rectangular steel pipe	4	94	98	M	4.5	0.041	566	621	91.1	0.42	611	1.08	1.02	Inventive example
3	Electric resistance welded steel pipe	69	5	74	P,M,A	13.8	0.076	362	427	84.8	0.55	431	1.19	1.09	Inventive example
4	Rectangular steel pipe	36	44	80	P	6.5	0.020	512	585	87.5	0.33	563	1.10	1.02	Inventive example
5	Rectangular steel pipe	50	41	91	P	5.0	0.024	505	592	85.3	0.40	566	1.12	1.00	Inventive example
6	Electric resistance welded steel pipe	22	61	83	P	7.2	0.060	529	563	94.0	0.57	603	1.14	1.06	Inventive example
7	Electric resistance welded steel pipe	88	9	97	M	12.5	0.032	344	<u>397</u>	86.6	0.29	365	1.06	0.97	Comparative example
8	Electric resistance welded steel pipe	14	53	<u>67</u>	P,M	5.3	0.071	623	639	<u>97.5</u>	0.62	642	1.03	1.07	Comparative example
9	Rectangular steel pipe	86	13	<u>99</u>	P	<u>15.1</u>	0.032	351	<u>394</u>	89.1	0.38	386	1.10	0.97	Comparative example

(continued)

No	Steel pipe type	Steel microstructure						Mechanical properties				Axial compressibility of steel pipe			Notes
		F fraction (%)	B fraction (%)	F+B fraction (%)	Remaining microstructure	Average grain size (μm)	CP	Yield stress σy (MPa)	Tensile strength (MPa)	Yield ratio (%)	Logarithmic standard deviation	Maximum stress intensity σmax (MPa)	Proof strength increase rate τ	Necessary lower limit of τ	
10	Electric resistance welded steel pipe	9	58	67	P,M	5.6	0.041	511	523	97.7	0.64	534	1.05	1.07	Comparative example
11	Rectangular steel pipe	93	0	93	P	15.7	0.103	327	386	84.7	0.75	330	1.01	1.02	Comparative example
12	Electric resistance welded steel pipe	81	13	94	M	7.6	0.093	481	512	93.9	0.69	495	1.03	1.04	Comparative example

- F fraction denotes the volume fraction of bainite, B fraction denotes the volume fraction of bainite, F+B fraction denotes the volume fraction of ferrite and bainite in total.
- In Remaining microstructure, P: pearlite, M: martensite, A: austenite.
- Underlined values are outside the scope of the present invention.

[0099] In Tables 4 and 5, Nos. 1 to 6 are examples of the present invention, and Nos. 7 to 12 are comparative examples.

[0100] In a hot-rolled steel sheet according to an example of the present invention, a steel microstructure at the center of the sheet thickness contained 70% or more and 98% or less by volume of ferrite and bainite in total, the remainder being one or two or more selected from pearlite, martensite, and austenite, had an average grain size of 15.0 μm or less, and had a CP value of 0.090 or less as determined using the specified formula (1). Furthermore, the tensile strength was 400 MPa or more, and the yield ratio was 90% or less. Furthermore, the logarithmic standard deviation of an equivalent plastic strain distribution after application of an 8.0% tensile strain was 0.70 or less.

[0101] An electric resistance welded steel pipe or a rectangular steel pipe according to an example of the present invention was produced from a hot-rolled steel sheet of an example of the present invention, and a steel microstructure at the center of the wall thickness contained 70% or more and 98% or less by volume of ferrite and bainite in total, the remainder being one or two or more selected from pearlite, martensite, and austenite, had an average grain size of 15.0 μm or less, and had a CP value of 0.090 or less as determined using the specified formula (1). Furthermore, the base metal portion or the flat portion had a tensile strength of 400 MPa or more, and the base metal portion or the flat portion had a yield ratio of 97% or less. Furthermore, the logarithmic standard deviation of an equivalent plastic strain distribution after application of a 4.0% tensile strain in the base metal portion or the flat portion was 0.60 or less. Furthermore, the proof strength increase rate τ (= σmax/σy) in the axial compression test satisfied $\tau \geq 4.0 \times (t/D) + 0.85$ (2) in the electric resistance welded steel pipes and $\tau \geq 3.0 \times (t/B) + 0.85$ (3) in the rectangular steel pipes. In Table 5, values obtained by substituting t and D of the electric resistance welded steel pipes and t and B of the rectangular steel pipes into the right sides of the formulae (2) and (3), respectively, are shown as the necessary lower limits of τ.

[0102] On the other hand, Comparative Example No. 7 had a C content below the scope of the present invention and had a tensile strength outside the scope of the present invention.

[0103] Comparative Example No. 8 had a C content above the scope of the present invention and had a total volume fraction of ferrite and bainite below the scope of the present invention. Consequently, the yield ratio was outside the scope of the present invention, the logarithmic standard deviation was outside the preferred range, and the proof strength increase rate did not reach the desired value.

[0104] Comparative Example No. 9 had Si and Mn contents below the scope of the present invention, had a total volume fraction of ferrite and bainite above the scope of the present invention, and had an average grain size above the scope of the present invention. Consequently, the tensile strength was outside the scope of the present invention.

[0105] Comparative Example No. 10 had Si and Mn contents above the scope of the present invention and had a total volume fraction of ferrite and bainite below the scope of the present invention. Consequently, the yield ratio was outside the scope of the present invention, the logarithmic standard deviation was outside the preferred range, and the proof strength increase rate did not reach the desired value.

[0106] Comparative Example No. 11 had an average cooling rate in the temperature range of 900°C or more in the hot rolling step below the suitable range of the production method, had an average grain size above the scope of the present invention, and had a CP value above the scope of the present invention. Consequently, the logarithmic standard deviation exceeded the preferred range of the present invention, and the proof strength increase rate did not reach the desired value. Furthermore, the tensile strength was below the scope of the present invention.

[0107] Comparative Example No. 12 had a cooling stop temperature in the hot rolling step above the suitable range of the production method and therefore had a CP value above the scope of the present invention. Consequently, the logarithmic standard deviation exceeded the preferred range of the present invention, and the proof strength increase rate did not reach the desired value.

[0108] Thus, with the steel composition and the microstructure within the scope of the present invention, it is possible to provide an electric resistance welded steel pipe or a rectangular steel pipe with high buckling resistance and a hot-rolled steel sheet used as a material thereof. Furthermore, it is possible to provide a line pipe or a building structure with high buckling resistance using the electric resistance welded steel pipe or the rectangular steel pipe.

Claims

1. A hot-rolled steel sheet having a chemical composition, on a mass percent basis,

C: 0.030% or more and 0.300% or less,
Si: 0.010% or more and 0.500% or less,
Mn: 0.30% or more and 2.50% or less,
P: 0.050% or less,
S: 0.0200% or less,
Al: 0.005% or more and 0.100% or less, and
N: 0.0100% or less,

the balance being Fe and incidental impurities,
wherein a steel microstructure at a center of a sheet thickness of the hot-rolled steel sheet contains 70% or more and 98% or less by volume of ferrite and bainite in total,
the remainder being one or two or more selected from pearlite, martensite, and austenite,
has an average grain size of 15.0 μm or less,
has a CP value of 0.090 or less as determined using the following formula (1),
has a tensile strength of 400 MPa or more, and
has a yield ratio of 90% or less.

CP = (total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less --> than 20 μm)/(total length of high-angle grain boundaries) (1)

2. The hot-rolled steel sheet according to Claim 1, further comprising, in addition to the chemical composition, on a mass percent basis, one or two or more selected from

Nb: 0.100% or less,
V: 0.100% or less,
Ti: 0.150% or less,
Cr: 0.50% or less,
Mo: 0.50% or less,
Cu: 0.50% or less,
Ni: 0.50% or less,
Ca: 0.0050% or less,
B: 0.0050% or less,
Mg: 0.020% or less,
Zr: 0.020% or less, and
REM: 0.020% or less.

3. The hot-rolled steel sheet according to Claim 1 or 2, wherein a logarithmic standard deviation of an equivalent plastic strain distribution after application of an 8.0% tensile strain is 0.70 or less.

4. An electric resistance welded steel pipe comprising a base metal portion and an electric resistance weld,

wherein the electric resistance welded steel pipe has a chemical composition containing, on a mass percent basis,
C: 0.030% or more and 0.300% or less,
Si: 0.010% or more and 0.500% or less,
Mn: 0.30% or more and 2.50% or less,
P: 0.050% or less,
S: 0.0200% or less,
Al: 0.005% or more and 0.100% or less, and
N: 0.0100% or less,
the balance being Fe and incidental impurities,
a steel microstructure at a center of a wall thickness of the electric resistance welded steel pipe contains 70% or more and 98% or less by volume of ferrite and bainite in total,
the remainder being one or two or more selected from pearlite, martensite, and austenite,
has an average grain size of 15.0 μm or less, and has a CP value of 0.090 or less as determined using the following formula (1), and
the base metal portion has a tensile strength of 400 MPa or more, and
the base metal portion has a yield ratio of 97% or less.

CP = (total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less --> than 20 μm)/(total length of high-angle grain boundaries) (1)

5. The electric resistance welded steel pipe according to Claim 4, further comprising, in addition to the chemical composition, on a mass percent basis, one or two or more selected from

Nb: 0.100% or less,
V: 0.100% or less,
Ti: 0.150% or less,
Cr: 0.50% or less,
Mo: 0.50% or less,
Cu: 0.50% or less,
Ni: 0.50% or less,
Ca: 0.0050% or less,
B: 0.0050% or less,
Mg: 0.020% or less,
Zr: 0.020% or less, and
REM: 0.020% or less.

6. The electric resistance welded steel pipe according to Claim 4 or 5, wherein the logarithmic standard deviation of the equivalent plastic strain distribution after application of a 4.0% tensile strain in the base metal portion is 0.60 or less.

7. A line pipe comprising the electric resistance welded steel pipe according to Claim 4 or 5.

8. A line pipe comprising the electric resistance welded steel pipe according to Claim 6.

9. A rectangular steel pipe comprising a flat portion and a corner portion,

wherein the rectangular steel pipe has a chemical composition containing, on a mass percent basis,
C: 0.030% or more and 0.300% or less,
Si: 0.010% or more and 0.500% or less,
Mn: 0.30% or more and 2.50% or less,
P: 0.050% or less,
S: 0.0200% or less,
Al: 0.005% or more and 0.100% or less, and
N: 0.0100% or less,
the balance being Fe and incidental impurities,
a steel microstructure at a center of a wall thickness of the rectangular steel pipe
contains 70% or more and 98% or less by volume of ferrite and bainite in total,
the remainder being one or two or more selected from pearlite, martensite, and austenite,
has an average grain size of 15.0 μm or less, and has a CP value of 0.090 or less as determined using the following formula (1), and
the flat portion has a tensile strength of 400 MPa or more, and
the flat portion has a yield ratio of 97% or less.

CP = (total length of high-angle grain boundaries in a region excluding crystal grains with a grain size of less than 20 μm)/(total length of high-angle grain boundaries) (1)

10. The rectangular steel pipe according to Claim 9, further comprising, in addition to the chemical composition, on a mass percent basis, one or two or more selected from

Nb: 0.100% or less,
V: 0.100% or less,
Ti: 0.150% or less,
Cr: 0.50% or less,
Mo: 0.50% or less,
Cu: 0.50% or less,
Ni: 0.50% or less,
Ca: 0.0050% or less,
B: 0.0050% or less,

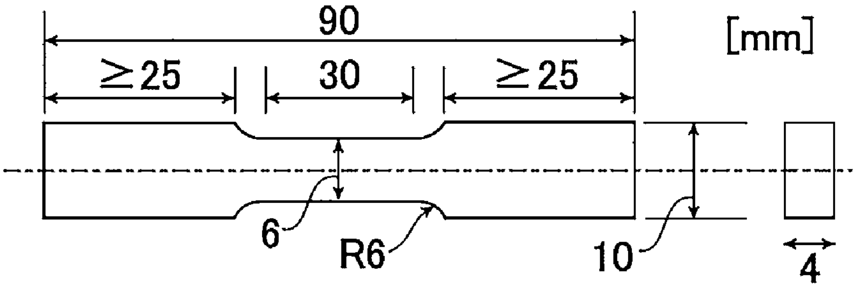
Mg: 0.020% or less,
Zr: 0.020% or less, and
REM: 0.020% or less.

11. The rectangular steel pipe according to Claim 9 or 10, wherein the logarithmic standard deviation of the equivalent plastic strain distribution after application of a 4.0% tensile strain in the flat portion is 0.60 or less.

12. A building structure comprising the rectangular steel pipe according to Claim 9 or 10 as a column member.

13. A building structure comprising the rectangular steel pipe according to Claim 11 as a column member.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/027298

A. CLASSIFICATION OF SUBJECT MATTER

C21D 8/02(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/06***(2006.01)i; ***C22C 38/58***(2006.01)i; ***B21B 1/22***(2006.01)i; ***B21C 37/08***(2006.01)i; ***B21C 37/15***(2006.01)i
FI: C22C38/00 301A; C22C38/06; C22C38/58; C22C38/00 301Z; B21B1/22 M; B21C37/08 A; B21C37/15 D; C21D8/02 A

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C21D8/02; C22C38/00; C22C38/06; C22C38/58; B21B1/22; B21C37/08; B21C37/15

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2021/100534 A1 (JFE STEEL CORP.) 27 May 2021 (2021-05-27) claims, paragraphs [0044], [0051], [0063]-[0065], tables 1-4, steel no. 17	1–8
Y	claims, paragraphs [0044], [0051], [0063]-[0065], tables 1-4, steel no. 17	9–13
Y	WO 2022/075026 A1 (JFE STEEL CORP.) 14 April 2022 (2022-04-14) claims, paragraph [0001]	9-13
A	KR 10-2020-0073343 A (POSCO CO., LTD.) 24 June 2020 (2020-06-24)	1-13

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
05 October 2023	**17 October 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/027298

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2021/100534 A1	27 May 2021	US 2022/0396856 A1 claims, paragraphs [0067]-[0069], [0076], [0088], [0089], tables 1-4, steel no. 17 EP 4029962 A1 KR 10-2022-0082041 A CN 114729426 A	
WO 2022/075026 A1	14 April 2022	KR 10-2023-0059820 A claims, paragraph [0001] CN 116323065 A	
KR 10-2020-0073343 A	24 June 2020	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- JP 7224351 A **[0010]**
- JP 5589885 B **[0010]**
- JP 6052374 B **[0010]**
- JP 7031477 B **[0010]**
- JP 2004330222 A **[0010]**